Chapter 6
Robotics in Alternative Energy

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6.1 Introduction

Energy is a fundamental task in the modern economy and society, and access to secure, reliable, and competitively priced energy has been for years a cornerstone in the global economic and social development.

Even though fossil fuels still play a major role in global energy needs, with its rising costs and policies to reduce greenhouse gas emissions, renewable and alternative energies are being looked into.

Achieving these clean energy ambitions will require the global community to successfully develop, adapt, commercialize, and deploy new technologies and processes across a range of energy applications. This will include not just energy generation but also transport energy storage, grid management, building design, and more efficient end-use technologies.

Actually, nations and manufacturers are turning their scientific research to alternative sources of power. Large-scale investment must be delivered to meet the growing demand for energy and improve energy productivity. Wind, solar, and biological continue their remarkable growth as alternative energies poised to supplant coal and oil. Nevertheless, until now, the cost per megawatt is higher than conventional sources.

In this context, the importance of robotics in the development and use of alternative energy is clear. It can be read robots as "critical to survival of alternative energy industry." They play a leading role in making ever-changing alternative energy more competitive. Robotics offers intelligent solutions in the manufacturing processes. Robotics in combination with control helps manufacturers to reduce costs, improve quality, and increase the productivity.

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For instance, solar companies are worried about the growing demand and the need to drive down the costs per watt requires that their automation process delivers high yields, high volume, quick change in capacity, flexibility to adapt to part variations, and consistent product inspection throughout the process. Robotics is a good partner for solar manufacturing: robots can integrate vision and inspection to cover different solar manufacturing needs. For example, one of the challenges with solar power is the amount of space panels take compared to other energy sources. Pointing solar panels toward the sun with trackers is a common way to get more energy from panels, particularly at large-scale farms. Robotic systems have been developed for tracking the sun along two dimensions, but at lower cost than traditional two-axis trackers. Robots are also used in the installation of large photovoltaic panel during the construction of a solar plant is done using a robotic arm. Another example is the robotic solutions incorporated in the construction and finishing of wind turbines. Fast and flexible robots allow not only to increase production but also to reach a better precision than with manual methods.

On the other hand, alternative energies can be used by robots as own energy source. Mobile robots have demonstrated their versatility in a wide range of applications. However, they have their limitations because of their reliance on traditional energy source which, by their very nature, cannot provide a convenient source of energy for all applications. For example, there are those robots which are reliant on electrical power supply, and they need to be plugged into an electrical power source all the time in order to be operational, which tends to limit their range of operation. In addition, electrical power supply may not always be available in certain situations, as for example, in disaster settings where such type of power is almost invariably interrupted or may be altogether unavailable due to damage to infrastructure, thereby making an electrically operated robot not a very viable option. The other alternative source of energy that could be employed to power a mobile robot is battery power, but even this option has its limitations, as batteries cannot provide a durable source of power over extended periods of time normally required for sustained operations which are necessary in search and rescue efforts. Yet another alternative energy source that could be employed to power a mobile robot is solar power. Robots can carry solar panels on it that help recharge its onboard battery. Once fully charge the robot can be used to the end, it has been designed. Nevertheless, this energy source has limitations. A solar-powered robot would be dependent on a constant light source to be able to function, and therefore, would not be viable for use in adverse light conditions, more especially in search and rescue operations where it would be needed most to seek out victims trapped underground or under rubble away from light. This limitation could be dealt if, for example, it is investigated the viability of a solar thermal energy storage system to overcome this time mismatch between solar energy availability and demand.

Anyway, the need for new investment in robotics and alternative energies is particularly critical to strike an appropriate balance in delivering energy security, facilitating economic development, and meeting clean goals.

This chapter is focused on three viable forms of alternative energy: solar power, wind power, and biological energy. Several aspects of these alternative forms of energy are described. The role of robotics in each case is also analyzed.

6.2 Solar Energy

Solar energy, radiant light, and heat from the sun, has been harnessed by humans since ancient times, using a range of ever-evolving technologies. Solar energy technologies include many different applications, which can make considerable contributions to solving some of the most urgent problems the world now faces (OECD/IEA 2011).

Solar energy is the energy obtained by capturing the electromagnetic radiation and the heat emitted by the sun. The amount of sun reaching the earth is higher than the total present need for energy on Earth. Approximately 30 % of the sun's radiation is reflected back to space while the rest is absorbed by clouds, oceans, and land masses.

Earth's land surface, oceans, and atmosphere absorb solar radiation, and this raises their temperature. Warm air containing evaporated water from the oceans rises, causing atmospheric circulation or convection. When the air reaches a high altitude, where the temperature is low, water vapor condenses into clouds, which rain onto the Earth's surface, completing the water cycle. The latent heat of water condensation amplifies convection, producing atmospheric phenomena such as wind, cyclones, and anti-cyclones. Sunlight absorbed by the oceans and land masses keeps the surface at an average temperature of 14 °C (Somerville 2007). By photosynthesis, green plants convert solar energy into chemical energy, which produces food, wood, and the biomass from which fossil fuels are derived (Vermass 2007).

However, although the Earth receives a lot of energy from the sun, it is only possible convert 10–15 % of this sun energy to usable energy (Pasqualetti and Miller 1984). This is clearly not as efficient as coal power, 40 % energy efficiency or wind power, 20 % energy efficiency. Furthermore, while coal energy and wind energy can be used for all day long, solar energy can only use during the day when there is sunlight. This situation can only be worse during winter.

Despite this, solar energy is deemed to be the future energy. Besides that, solar energy is the cleanest energy because of it is totally pollution-free, and for that, it is considered as a perfect solution for the energy needs in the world.

This energy is clean and easy to maintain. It is a so-called renewable energy and in particularly belongs to the group known as clean energy or green energy, but at the end of its life, for example, the solar panels used in thermal plants can be a difficult pollutant recyclable waste today.

In 2011, the International Energy Agency said that “the development of affordable, inexhaustible and clean solar energy technologies will have huge longer-term benefits. It will increase countries' energy security through reliance on an indigenous, inexhaustible and mostly import-independent resource, enhance sustainability, reduce pollution, lower the costs of mitigating climate change, and keep fossil fuel prices lower than otherwise. These advantages are global. Hence the additional costs of the incentives for early deployment should be considered learning investments; they must be wisely spent and need to be widely shared" (OECD/IEA 2011).

Solar energy represents a very abundant and inexhaustible energy resource to mankind, relatively well-spread over the globe. Its availability is greater in warm and sunny countries. These countries will likely contain about seven billion inhabitants by 2050 versus two billion in cold and temperate countries (including most of Europe, Russia, and parts of China and the United States of America).

The cost of the production of the solar energy depends on the used solar energy technology. There are many different forms of solar energy production as, solar heating, solar photovoltaic, solar thermal electricity, and solar architecture, with different advantages and disadvantages.

The costs of solar energy have been falling rapidly and are entering new areas of competitiveness. For example, solar thermal electricity and solar photovoltaic electricity are every time more competitive against oil-fueled electricity generation. However, in the most markets, solar electricity is not yet able to compete without specific incentives.

6.2.1 Applications of Solar Energy

Solar technologies are broadly characterized as either passive solar or active depending on the way they capture, convert, and distribute solar energy. **Active** *solar techniques* include, for example, the use of photovoltaic panels, solar thermal collectors, pumps, and fans to harness the energy. *Passive solar techniques* include orienting a building to the sun, selecting materials with favorable thermal mass or light dispersing properties, and designing spaces that naturally circulate air. These features must be adequate to the local climate and environment, in order to obtain the best comfortable temperature range.

Active solar technologies increase the supply of energy and are considered supply-side technologies, while passive solar technologies reduce the need for alternate resources and are generally considered demand-side technologies (Philibert 2005).

6.2.1.1 Solar Energy and Agriculture

Nowadays, the agriculture uses the capture of solar energy in order to optimize the productivity of plants. Techniques such as timed planting cycles, tailored row orientation, staggered heights between rows, and the mixing of plant varieties can improve crop yields (Jeffrey 1999; Kaul et al. 2001). The solar energy is very important to the plants.

Applications of solar energy in agriculture aside from growing crops include pumping water and drying crops. More recently, the technology has been embraced to use the energy generated by solar panels to power grape presses. But the most principal application is in the greenhouse.

A *greenhouse* converts solar light to heat, enabling year-round production and the growth (in enclosed environments) of specialty crops and other plants not naturally suited to the local climate.

A greenhouse is a structure with different types of covering materials, such as a glass or plastic roof and frequently glass or plastic walls. It heats up because incoming visible solar radiation from the sun and this radiation is absorbed by plants, soil, and other things inside the building. Air warmed by the heat from hot interior surfaces is retained in the building by the roof and wall (see the Fig. 6.1).

Thus, the primary heating mechanism of a greenhouse is convection. This can be demonstrated by opening a small window near the roof of a greenhouse: the temperature drops considerably. This used principle is the basis of the auto ventilation automatic cooling system.

6.2.1.2 Solar Lighting

In the twentieth century, artificial lighting became the main source of interior illumination but delighting techniques and hybrid solar lighting solutions are ways to reduce energy consumption.

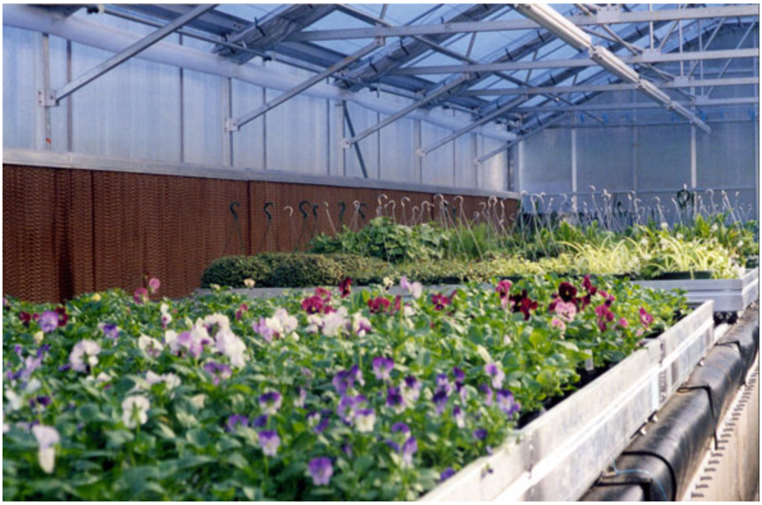

Fig. 6.1 Greenhouse (this is a figure from the Wikimedia Commons)

Day lighting systems collect and distribute sunlight to provide interior illumination. This passive technology directly offsets energy use by replacing artificial lighting and indirectly offsets non-solar energy use by reducing the need for air-conditioning. Day lighting design implies careful selection of window types, sizes, and orientation. Individual features include saw tooth roofs, clerestory windows, light shelves, skylights, and light tubes. They may be incorporated into existing structures, but are most effective when integrated into a solar design package that accounts for factors such as glare, heat flux, and time-of-use. When delighting features are properly implemented they can reduce lighting-related energy requirements by 25 % (Apte et al. 2003).

Hybrid solar lighting is an active solar method of providing interior illumination. These systems collect sunlight using focusing mirrors that track the sun and use optical fibers to transmit it inside the building to supplement conventional lighting. Applications of these systems are able to transmit 50 % of the direct sunlight received (Muhs and Oak Redge National Lab 2000).

6.2.1.3 Solar Thermal for Water Heating

Solar hot water systems use sunlight to heat water. In low geographical latitudes, it is possible to generate until 70 % of the domestic hot water. The most common types of solar water heaters are *evacuated tube collectors* (44 %), *glazed flat plate collectors* (34 %) generally used for domestic hot water, and *unglazed plastic collectors* (21 %) used mainly to heat swimming pools (see the Fig. 6.2) (Weiss et al. 2005).

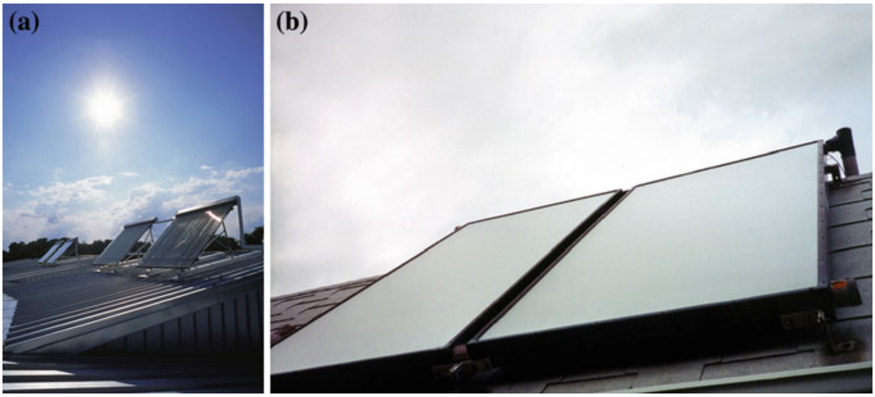

Fig. 6.2 Water heating with solar thermal. **a** Evacuated tube collectors. **b** Glazed Flat plates collectors (this is a figure from the Wikimedia Commons)

6.2.1.4 Solar Thermal for Heating, Cooling, and Ventilation

The *heating, ventilation, and air-conditioning systems* account an important part of the energy used in commercial buildings and in residential buildings. Solar heating, cooling, and ventilation technologies can be used to offset a portion of this energy. Thermal mass is any material that can be used to store heat from the sun in the case of solar energy, as for example, stone, cement, and water. They have been used in arid climates, or warm temperate regions, to keep buildings cool by absorbing solar energy during the day and radiating stored heat to the cooler atmosphere at night (see the Fig. 6.3).

A *solar chimney* is a passive solar ventilation system composed of a vertical shaft connecting the interior and exterior of a building. As the chimney warms, the air inside is heated causing an updraft that pulls air through the building. Performance can be improved by using glazing and thermal mass materials (Bright 1977) in a way that mimics greenhouses.

Fig. 6.3 Solar house (this is a figure from the Wikimedia Commons)

6.2.1.5 Solar Thermal for Water Treatment

Solar distillation can be used to make saline or brackish water potable. *Solar water disinfection* involves exposing water-filled plastic bottles to sunlight for several hours. Exposure times vary depending on weather and climate from a minimum of six hours to two days during fully overcast conditions.

6.2.1.6 Solar Thermal for Cooking

Solar cookers use sunlight for cooking, drying, and pasteurization. They can be grouped into three broad categories: *box cookers*, *panel cookers,* and *reflector cookers* (Anderson and Palkovic 1994).

The simplest solar cooker is the box cooker. A basic box cooker consists of an insulated container with a transparent lid. It can be used effectively with partially overcast skies and will typically reach temperatures of 90–150 °C.

Panel cookers use a reflective panel to direct sunlight onto an insulated container and reach temperatures comparable to box cookers.

Reflector cookers use various concentrating geometries (dish, trough, Fresnel mirrors) to focus light on a cooking container. These cookers reach temperatures of 315 °C and above but require direct light to function properly and must be repositioned to track the sun (see the Fig. 6.4).

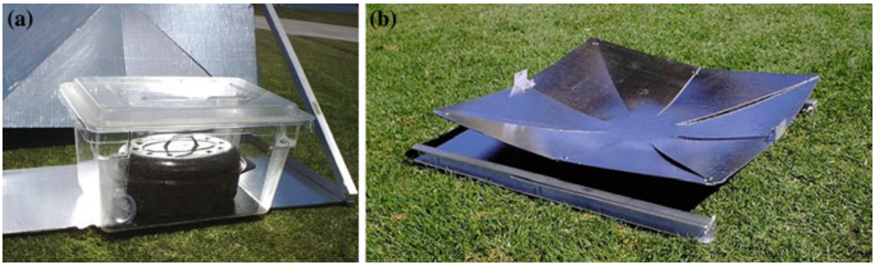

Fig. 6.4 Cooking with solar thermal. **a** Box cooker. **b** Reflector cooker (this is a figure from the Wikimedia Commons)

6.2.1.7 Solar Power

Solar power is the conversion of sunlight into electricity, either directly using photovoltaic panels, or indirectly using concentrated solar power.

Concentrated Solar Power

Concentrating solar power systems use lenses or mirrors and tracking systems to focus a large area of sunlight into a small beam. The concentrated heat is then used as a heat source for a conventional power plant. A wide range of concentrating technologies exists, but the most developed are the parabolic trough (See the Fig. 6.5).

Various techniques are used to track the sun and focus light. In all of these systems, a working fluid is heated by the concentrated sunlight and is then used for power generation or energy storage (Martin et al. 2005).

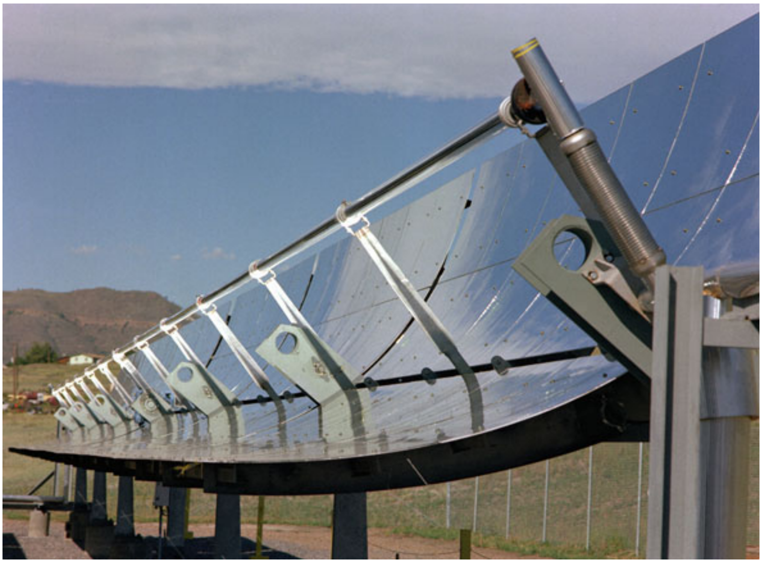

Fig. 6.5 Parabolic through (this photograph is from Warren Gretz, NREL 04511)

Photovoltaic Panel

Photovoltaic panel is a method of generating electrical power by converting solar radiation into direct current electricity using semiconductors that exhibit the photovoltaic effect (see the Fig. 6.6).

Photovoltaic power generation employs solar panels composed of a number of cells containing a photovoltaic material (Mark 2009). Photovoltaic panels are best known as a method for generating electric power by using solar cells to convert energy from the sun into a flow of electrons.

Photovoltaic panel is one of the fastest-growing power generation technologies in the world. Driven by advances in technology and increases in manufacturing scale and sophistication, the cost of photovoltaic has declined steadily.

Net metering and financial incentives, such as preferential feed-in tariffs for solar-generated electricity have supported solar photovoltaic panel installations in many countries. Some representative advantages of the photovoltaic panels are as follows:

- Photovoltaic panel systems can be designed for a variety of applications and operational requirements and can be used for either centralized or distributed power generation.

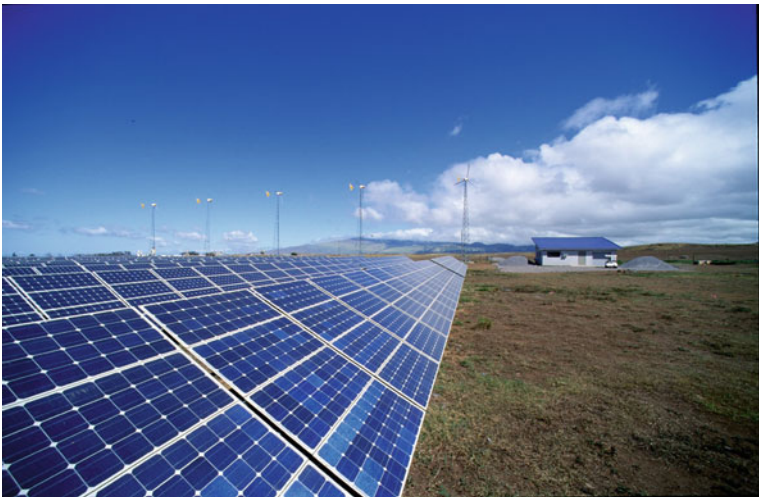

Fig. 6.6 Photovoltaic panels (this photograph is from SunPower, NREL 13823)

- Photovoltaic panel systems have no moving parts and are modular, easily expandable, and even transportable in some cases.
- Energy independence and environmental compatibility are two attractive features of photovoltaic panel systems.
- The fuel (sunlight) is free, and no noise or pollution is created from operating photovoltaic panel systems.
- Photovoltaic panel systems that are well designed and properly installed require minimal maintenance and have long service lifetimes.

In the other way, some representative disadvantages of the photovoltaic panels are as follows:

- High cost of photovoltaic panel modules and equipment (as compared to conventional energy sources) is the primary limiting factor. Consequently, the economic value of photovoltaic panel systems is realized over many years.
- In some cases, the surface area requirements for photovoltaic panel arrays may be a limiting factor.
- Due to the diffuse nature of sunlight and the existing sunlight to electrical energy conversion efficiencies of photovoltaic devices, special surface area requirements are needed.
- In climates with many cloudy days, power output is reduced from its full potential, which means that your initial investment takes longer to pay back.

6.2.1.8 Solar Chemical

Solar chemical processes use solar energy to drive chemical reactions. These processes offset energy that would otherwise come from a fossil fuel source and can also convert solar energy into storable and transportable fuels. Solar-induced chemical reactions can be divided into *thermochemical* or *photochemical* (Bolton 1997).

A variety of fuels can be produced by artificial photosynthesis (Wasielewski 1992). The multielectron catalytic chemistry involved in making carbon-based fuels (such as methanol) from reduction of carbon dioxide is challenging. A feasible alternative is hydrogen production from protons, though use of water as the source of electrons (as plants do) requires mastering the multielectron oxidation of two water molecules to molecular oxygen (Hammarstrom and Hammes-Schiffer 2009).

Hydrogen production technologies are a very significant area of solar chemical research since the 1970s. Aside from electrolysis driven by photovoltaic or photochemical cells, several thermochemical processes have also been explored.

Other alternative is the *photoelectrochemical cells*, which consist of a semiconductor, typically titanium dioxide, immersed in an electrolyte. When the semiconductor is illuminated, an electrical potential develops. There are two types of photoelectrochemical cells: photoelectric cells that convert light into electricity and photochemical cells that use light to drive chemical reactions such as electrolysis (Bolton 1997).

6.2.1.9 Solar Vehicles

A *solar vehicle* is an electric vehicle powered completely or significantly by direct solar energy. Usually, photovoltaic cells contained in solar panels convert the sun's energy directly into electric energy. Solar power may be also used to provide power for communications or controls or other auxiliary functions.

Solar vehicles are not sold as practical day-to-day transportation devices at present, but are primarily demonstration vehicles and engineering exercises. However, indirectly solar-charged vehicles are widespread and solar boats are available commercially (see the Fig. 6.7).

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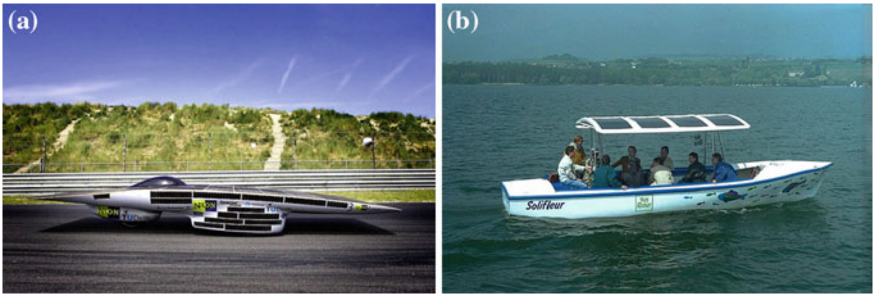


Fig. 6.7 Solar vehicles. **a** Solar car. **b** Solar boat (this is a figure from the Wikimedia Commons)

6.2.2 Control and Robotics in Solar Energy

Several variables, such as the sun's position and atmospheric conditions, can affect the amount of solar energy you can harness. To make the most of the solar energy available, you can use a control system to track the path of the sun while monitoring important data such as ambient conditions and power quality.

Currently, most large systems incorporate single-axis trackers. Single-axis tracking that follows the azimuth of the sun in order to increase efficiency of the system. In some systems, solar panels are made to face the sun directly (see the Fig. 6.8). Other systems consist of mirrors that concentrate the sun's rays by reflecting them onto a central solar collector.

Sun tracking has two benefits: to maximize the amount of energy that you can harness and to distribute the solar flux evenly on a solar collector's surface, thus ensuring a healthier system.

A sun-tracking system can be active or passive. Active tracking signifies that a light-intensity sensor provides solar irradiance feedback for the system to optimize the position of the solar collector.

Passive tracking uses the predetermined known path of the sun to control the direction of the solar collector. Astronomers have provided algorithms that determine the position of the sun based on date, time, and their location on the earth. These algorithms take into account the rotation of the earth and revolution

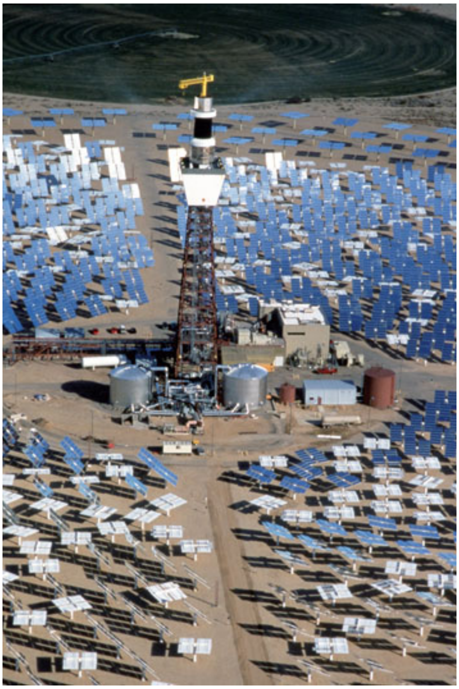


Fig. 6.8 Solar plant (this photograph is from Hugh Reilly, NREL 02186)

around the sun (seasonal changes) for different longitudes and latitudes and can provide the azimuth and elevation of the sun.

The main components of a *control tracking system* are as follows:

- Sun-tracking algorithm: This algorithm calculates the azimuth and elevation of the sun and outputs the direction that the solar panel or reflector should face. It can either calculate the sun's position using real-time light-intensity readings or using predetermined knowledge of the sun's movement. It is controlled the direction of the panel or mirror.
- Motion control system: In the motion control portion of the system, a motor is driven to rotate the solar panel while an encoder is used to read the current position of the panel. These components are used to ensure that the panel is facing the desired azimuth and elevation.
- Power quality monitoring system: Keeping track of the current, voltage, and power generated by a solar cell is important to monitor efficiency and system health. When you use a solar panel for sun tracking, you can integrate power monitoring into the system. With reflectors, this is not necessary because the power is not harnessed at this location. You can also use these current and voltage readings to perform maximum power point tracking.
- Ambient condition sensing system: Because ambient conditions affect the operating point and efficiency of solar power harvesting, you need to acquire and log readings from sensors that measure light intensity (solar radiance), temperature, humidity, and so on. You also need pyranometers that read light intensity if you are directly using this value in the sun-tracking algorithm.

On the other hand, *industrial robots* effectively accommodate the rapid (and constant) evolution of solar energy technology. Simulation software makes possible for solar energy system companies to change products and processes quickly and seamlessly.

Solar panel manufacturers increasingly rely on robots for a host of material handling applications. Industrial robots provide ideal solutions for precision-driven assembly and heavy palletizing needs, while still assisting with inspection and quality control jobs. Robotic vision eliminates the need for complex elements and plays a key role in many solar energy manufacturing applications, from locating and inspecting parts, to guiding robots.

There are two types of relevant robots used in solar plant:

- *Robotic Cell and Wafer Handling*: Solar cells and silicon wafers are delicate items that require delicate handling solutions. Robots are capable of assembling these solar energy system components with greater gentleness and precision than is possible manually. They maintain consistent production speeds and repeatability necessary for solar cell and silicon wafer assembly/handling.
- *Robots for Solar Panel Assembly* (see the Fig. 6.9): Manufacturers benefit from using robots when it comes to constructing solar panels, which are often very

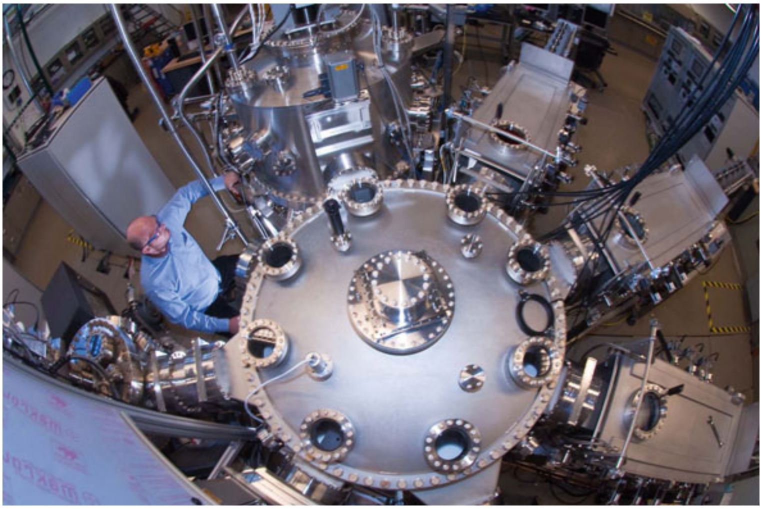


Fig. 6.9 Robot for solar panel assembly (this photograph is from Pat Corkery, NREL 17161)

complex in design. Once again, consistency and delicate handling are very important. Every component must be carefully aligned. Robots are also very useful for handling heavy glass panels and other solar panel components with care.

6.3 Wind Energy

The conversion of wind energy to various other useful forms, like electricity, is known as wind power. Wind energy is converted into these forms using wind turbines which convert the kinetic energy in the wind into mechanical power. This mechanical power can be used for specific tasks (such as grinding grain or pumping water) or can be converted into electricity using a generator.

The first use of wind energy was through windmills. Windmills had engines used to produce energy using wind. This energy was usually used in rural and agricultural areas for grinding, pumping, hammering, and various farm needs. Even today, wind energy is used in large-scale wind farms (see the Fig. 6.10) to provide electricity to rural areas and other far-reaching locations.

Wind energy is being used extensively in areas like Denmark, Germany, Spain, India, and in some areas of the United States of America. It is one of the largest forms of green energy used in the world today. Wind energy is highly practical in places where the wind speed is 10 mph.

Fig. 6.10 Wind farms have sprung up in recent year (this is a photograph from Iberdrola Renewables, Inc/NREL 15177)

6.3.1 Wind Power: Advantages and Disadvantages

Wind energy offers many advantages, which explains why it is one of the fastest-growing energy sources in the world. *Main advantages* of wind energy are listed below (U.S. Department of Energy 2011):

- Wind energy is renewable.
- It is widely distributed, cheap, and also helps in reducing toxic gas emissions. It is getting cheaper to produce wind energy. Wind energy may soon be the cheapest way to produce energy on a large-scale.
- The cost of producing wind energy is coming down continuously.
- Along with economy, wind energy is also said to diminish the greenhouse effect. Wind energy generates no pollution. It is friendly to the surrounding environment, as no fossil fuels are burnt to generate electricity from wind energy.
- Wind energy could be readily available around the globe, and therefore, there would be no need of dependence for energy for any country.
- Wind energy may be the answer to the globe's question of energy in the face of the rising petroleum and gas prices.

Although wind energy is one of the renewable sources of energy, there are certain constraints which pose a challenge in using it to its full potential. Some *disadvantages* for wind energy are the following (US Department of Energy 2011):

- Wind turbines generally produce less electricity than the average fossil fueled power station, requiring multiple wind turbines to be built in order to make an impact. A large number of turbines have to be built to generate a proper amount of wind energy.

- Many potential wind farms, places where wind energy can be produced on a large-scale, are far away from places for which wind energy is best suited. Therefore, the economical nature of wind energy may take a beating in terms of costs of new substations and transmission lines.
- The noise pollution from commercial wind turbines is sometimes similar to a small jet engine. This is fine if you live miles away, where you will hardly notice the noise, but what if you live within a few hundred meters of a turbine? This is a major disadvantage.
- Wind turbine construction can be very expensive and costly to surrounding wildlife during the build process. In this sense, protests usually confront any proposed wind farm development. Wind turbines typically cover vast expanses of landscapes, and that has received much public discontent (University of Michigan). Typically, land is viewed as sacred, has some esthetic value, or is under some political restrictions can lead to problems with the implementation of such projects—simply because turbines take up a lot of space and are ugly. People feel the countryside should be left intact for everyone enjoy its beauty.
- The amount of wind supplied to a place and the amount of energy produced from it will depend on various factors like wind speeds and the turbine characteristics. Some critics also wonder whether wind energy can be used in areas of high demand.

6.3.2 Control and Robotics in Wind Energy

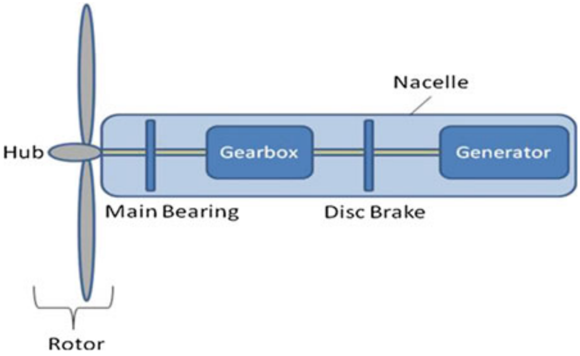
In order to understand the role of control and robotics in wind energy, a general overview of the wind turbine operation is presented (National Instruments 2008).

Simply stated, a wind turbine works the opposite of a fan. Instead of using electricity to make wind, like a fan, wind turbines use wind to make electricity. A wind turbine converts the kinetic energy from the wind into mechanical energy. This mechanical energy is then converted into electricity that is sent to a power grid. The turbine components responsible for these energy conversions are the rotor and the generator.

Figure 6.11 shows the major components of a wind turbine: gearbox, generator, hub, rotor, low-speed shaft, high-speed shaft, and the main bearing. The components are all housed together in a structure called the nacelle.

The rotor is the area of the turbine that consists of both the turbine hub and blades. As wind strikes the turbine's blades, the hub rotates due to aerodynamic forces. This rotation is then sent through the transmission system to decrease the revolutions per minute. The transmission system consists of the main bearing, high-speed shaft, gearbox, and low-speed shaft. The ratio of the gearbox determines the rotation division and the rotation speed that the generator sees. For example, if the ratio of the gearbox is N to 1, then the generator sees the rotor speed divided by N. This rotation is finally sent to the generator for mechanical-to-electrical conversion.

Fig. 6.11 Components of a wind turbine, courtesy of National Instruments (*NI*)

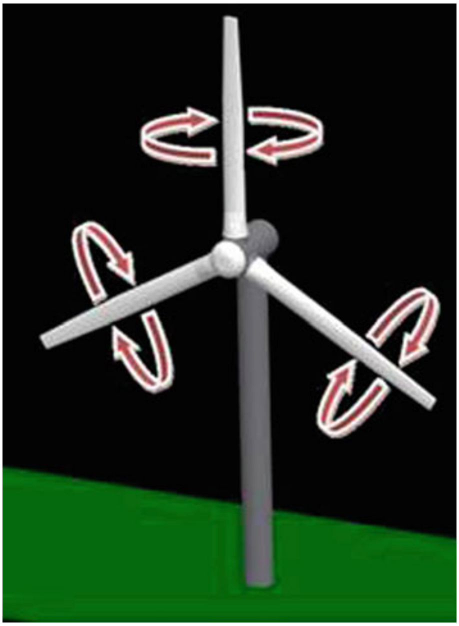


Wind turbine control is necessary to ensure low maintenance costs and efficient performance. The control system also guarantees safe operation, optimizes power output, and ensures long structural life.

Different control methods to either optimize or limit power output can be used. Turbine rotational speed and the generator speed are two key areas that must be controlled for power limitation and optimization. Different techniques used in these areas to control a turbine are briefly described:

- *Blade angle adjustment*: it is also called pitch control (see the Fig. 6.12). The purpose of pitch control is to maintain the optimum blade angle to achieve certain rotor speeds or power output.

Fig. 6.12 Pitch adjustment, courtesy of National Instruments (*NI*)



- *Turbine rotation adjustment*: it is also called yaw control (see the Fig. 6.13). Yaw refers to the rotation of the entire wind turbine in the horizontal axis. Yaw control ensures that the turbine is constantly facing into the wind to maximize the effective rotor area and, as a result, power.
- *Speed control*: it deals with the electrical subsystem. This dynamic control is achieved with power electronics, or, more specifically, electronic converters that are coupled to the generator. The two types of generator controls are stator and rotor. The stator and rotor are the stationary and non-stationary parts of a generator, respectively. In each case, the stator or rotor is disconnected from the grid to change the synchronous speed of the generator independently of the voltage or frequency of the grid. Controlling the synchronous generator speed is the most effective way to optimize maximum power output at low wind speeds.

As mentioned before, the main goal of any control method (pitch, yaw, rotational speed control) is to optimize or limit the power extracted from the wind. Wind turbine control is essential for optimal performance, safe operation, and structural stability.

It is worth to note that a common used tool by the control designer is the wind turbine simulators, which provides researchers with a controlled test environment for wind turbine generators, inverters, and systems operations, resulting in improvement research productivity. These simulators provide an infrastructure for the development of advanced control methodologies to improve aspects of system performance such as maximum power extraction from wind or solar sources (Neammanee et al. 2007; Abbas et al. 2010).

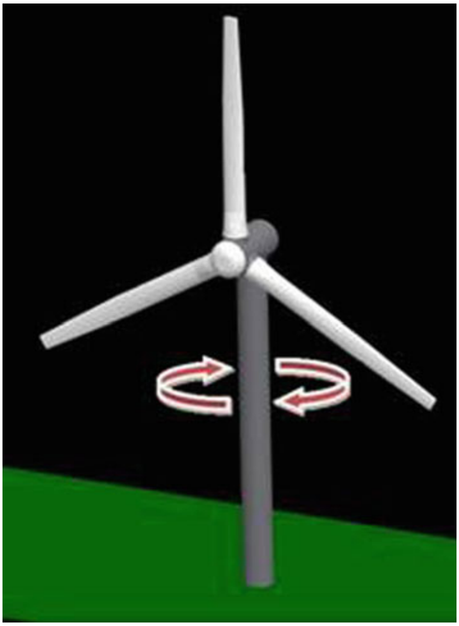


Fig. 6.13 Yaw adjustment, courtesy of National Instruments (*NI*)

On the other hand, due to the scale of wind turbine blades and tower pose, industrial robots have proved invaluable tools for nearly every aspect of wind turbine manufacturing. Wind energy system manufacturers incorporate robotic solutions in both the construction and finishing of wind turbines (Bennett 2010).

- Precision is required for drilling and finishing of surfaces of the nacelle, the housing that contains the generating components, and the very long blades.
- When putting large turbine blades onto nacelles, robots need precision to ensure correct and consistent alignment. By using intelligent robotics with integrated vision and force control allows the robot to precisely locate and drill holes and finish mating surfaces.
- Robots help overcome the large size of wind turbine assemblies. As Blanchette states (Bennett 2011) “Windmill blades are huge. Processes to the exterior are done less practically with hard automation or by manual labour. Putting a robot on an elevator is much simpler.”
- Robots are also used in sanding applications to assure proper surface preparation of the wind turbine blades. This is a critical task because imperfections on turbine blade surfaces cause inefficient eddy air currents over the blade.
- Nacelles and towers are painted, polished, and buffed robotically. With robots, these issues are more consistent and quick, allowing companies to match quality requirements.

In this way, fast and flexible robots allow wind turbine manufacturers to increase production and meet lead times more efficiently, as well as adjust quickly to product changes. The precision and consistent performance possible with robots beat manual methods, vastly improving quality control. Moreover, as wind turbine blades and other components must be finished (painted, sanded, polished, debarred) to perfection, high-quality standards are necessary to maintain the blade balance, extend component longevity, and withstand environmental wear and tear. Robots are helping wind turbine manufacturers achieve the best possible results.

Robotics is also presents in the battery manufacturing which is required to store power produced by wind systems. Wind systems, in the same way that solar systems, are not always generating energy. The use of battery systems to absorb some of this energy as it is generated to be utilized later when the wind is not blowing is a technology in continuous advancement. As batteries contain hazardous elements that people should not directly handle, intelligent robots are required to handle them successfully.

Even though the cost of producing power with wind turbines continues to drop due to the control and optimization techniques improvements and robotics advancements, many engineers feel that the overall design of turbines is still far from optima. Anyway, newer technologies are making the extraction of wind energy much more efficient.

6.4 BioEnergy

Biological energy is the energy that is derived from recently living organisms, such as wood, plant matter, or gases produced by microorganisms. This renewable energy is the so-called bioenergy.

Biological energy sources can be broken down into the categories biomass and biofuel. *Biomass* is produced directly by the living organisms. *Biofuel* is fuel derived from biomass through various processes for the purpose of making transportation of fuel easier, more efficient, or optimized for certain uses.

6.4.1 Biological Energy: Advantages and Disadvantages

Although the burning or conversion of biomass does not fully relieve pollution of the atmosphere, it does have several major benefits. In many regions, biomass is more reliable than solar or wind energy. This is because the energy in plants is captured and stored, while in solar and wind energy, this must be done by manufactured technology.

The main advantages and disadvantages of biological energy are summarized in Borrill (2011). The main advantages are as follows:

- Biomass is a completely renewable resource. Fuel can be produced using grains and plant waste that would otherwise go unused. Many of these plants and grains can be replaced the very next growing season.
- Organic waste exists in abundance and can be used to produce biomass energy. Large amount of solid waste that is currently just dumped into landfills can be used as a source of energy.
- Waste products generated by human activity (paper and household garbage) can be collected and used as biomass to generate energy. This reduces the amount of waste generated and sent to landfills.
- Biomass can be used in many forms: to produce heat, electricity, or other forms of energy. It can be processed and refined to produce alcohols and methane gas, both of which make clean burning sources of energy.
- Biomass energy can save a great deal of money in transportation costs alone. It can be used in the same area in which it is produced. In this way, it is more cost effectively than having huge pipelines or long-distance transmission lines.
- Perhaps, the *most significant advantage of bioenergy* is that it is a potentially renewable natural resource that would help supply energy needs indefinitely.

However, there are some disadvantages to using bioenergy:

- Direct burning of biomass as fuel can release carbon dioxide and other greenhouse gases into the atmosphere (possibly contributing to the problem of global warming). To avoid this effect, converting biomass into a different form of fuel (alcohol or methane) is necessary. This conversion process requires energy input that can make biomass energy more costly than beneficial on a small scale.

- The cost of accumulating and harvesting biomass in its raw form is currently much higher (compared to extracting fossil fuels). It takes time and money to gather and transport biomass to a central point for processing into fuel.
- A biomass power plant would require a great deal of space to accommodate the various stages of collection and conversion of mass into fuel before burning it to produce electricity.
- Water can also be a problem as it would require large quantities to handle the recycling process for waste materials.
- Perhaps, *the major difficulty with bioenergy* is the same problem that has arisen with recycling. People will not demand bioenergy until there is a considerable cost saving in doing so, but there will not be much savings until there is a much larger demand for bioenergy.

6.4.2 Biomass Conversion Process to Useful Energy

There are a number of technological options available to make use of a wide variety of biomass types as a renewable energy source. Conversion technologies may release the energy directly, in the form of heat or electricity, or may convert it to another form, such as liquid biofuel or combustible biogas. While for some classes of biomass resource there may be a number of usage options, for others there may be only one appropriate technology.

Three common conversions to transform biomass to useful energy are the thermal, chemical, and biochemical conversion.

Thermal conversion is the process in which heat is the dominant mechanism to convert the biomass into another chemical form. The basic alternatives of

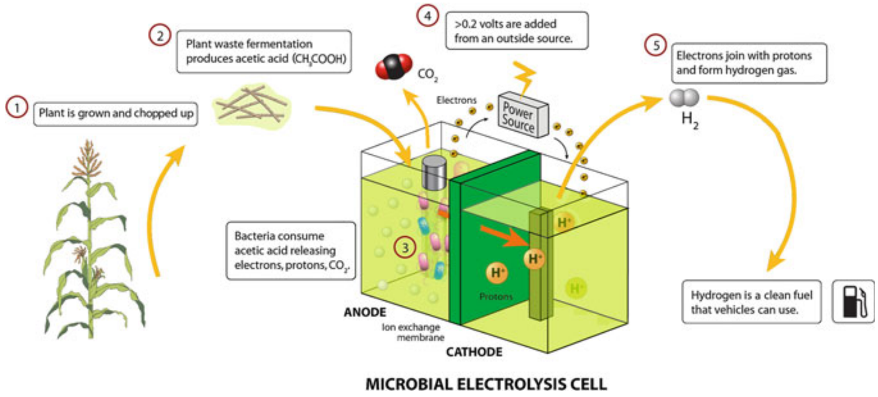

① Plant is grown and chopped up
② Plant waste fermentation produces acetic acid (CH_3COOH)
③ Bacteria consume acetic acid releasing electrons, protons, CO_2.
④ >0.2 volts are added from an outside source.
⑤ Electrons join with protons and form hydrogen gas.
CO_2
Electrons
Power Source
H_2
H^+
Protons
ANODE
Ion exchange membrane
CATHODE
Hydrogen is a clean fuel that vehicles can use.
MICROBIAL ELECTROLYSIS CELL

Fig. 6.14 A microbial electrolysis cell can be used to directly make hydrogen gas from plant matter (this is a figure from Wikimedia Commons)

combustion, torrefaction, pyrolysis, and gasification are separated principally by the extent to which the chemical reactions involved are allowed to proceed (mainly controlled by the availability of oxygen and conversion temperature).

There are a number of other less common, more experimental or proprietary thermal processes that may offer benefits such as hydrothermal upgrading and hydroprocessing. Some have been developed for use on high-moisture-content biomass, including aqueous slurries, and allow them to be converted into more convenient forms. Some of the applications of thermal conversion are combined heat and power and cofiring. In a typical biomass power plant, efficiencies range from 20 to 27 % (Dave 2010).

Chemical conversion. A range of chemical processes may be used to convert biomass into other forms, such as to produce a fuel that is more conveniently used, transported, or stored, or to exploit some property of the process itself.

Biochemical conversion. As biomass is a natural material, many highly efficient biochemical processes have developed in nature to break down the molecules of which biomass is composed, and many of these biochemical conversion processes can be harnessed (see the Fig. 6.14).

Biochemical conversion makes use of the enzymes of bacteria and other micro-organisms to break down biomass. In most cases microorganisms are used to perform the conversion process: anaerobic digestion, fermentation, and composting. Other chemical process that converts straight and waste vegetable oils into biodiesel is transesterification (biomassenergycentre.org.uk conversion technologies). Another way of breaking down biomass is by breaking down the carbohydrates and simple sugars to make alcohol. However, this process has not been perfected yet. Scientists are still researching the effects of converting biomass.

6.4.3 Biofuel

One of the major goals of bioenergy is to produce a fuel that has a carbon neutral or even negative impact on the atmosphere. Plants and other organisms take carbon from the atmosphere as they grow. When biomass or biofuels are consumed for energy, carbon is then released back into the atmosphere. This is in stark contrast to fossil fuels which release carbon that has been out of the atmosphere for thousands of years.

Although one of the major goals of biofuels is producing fuel that has a neutral or negative carbon footprint, but this can be offset by certain things. Crops used for biofuel production use carbon from the atmosphere which is released during combustion. This cycle does not take into account nitrogen oxide and other pollutants and green gases released during the production and use of fertilizers, pesticides, and other agricultural aids that may be used.

Land use is another major factor in the environmental impact of biological energy. Growing crops for fuel takes large amounts of land that could otherwise be used for food crops or even preserved in a natural state. Using land to produce crops also depletes soil of nutrients of and can have major impacts on local water supplies due to leaching of chemicals from pesticides and fertilizers.

Biofuels in particular also have an impact on the supply of food crops which can cause changes in the price of food locally and globally. When corn is being used to produce ethanol instead of eaten, the supply of corn is diminished and thus the price increases. Some studies have shown that this impact is not negligible and is already contributing to famine and negative food market fluctuations.

6.4.3.1 Types of Biofuels

All biofuels are derived from organic matter. One exception is cutting edge technology like microbes that convert water and carbon into hydrocarbons (gasoline and more), but these still use organic organisms to produce fuel. Most biofuels are produced from plant crops or waste with sugar cane and corn being popular choices. This biomass is altered by chemical or biological processes to arrive at the final biofuel product.

Probably, the most popular biofuel in the average person's life is direct use of biomass through burning. Wood (biomass) is simply ignited and the heat energy produced can be used for cooking and warmth.

Ethanol is a common biofuel that is most commonly produced by fermenting biomass with specific yeast that consumes sugars and produces ethanol as a waste product. Sugar cane and corn are popular biomass crops used to produce ethanol. A pilot plant to obtain ethanol from biomass is displayed in Fig. 6.15. Ethanol is a

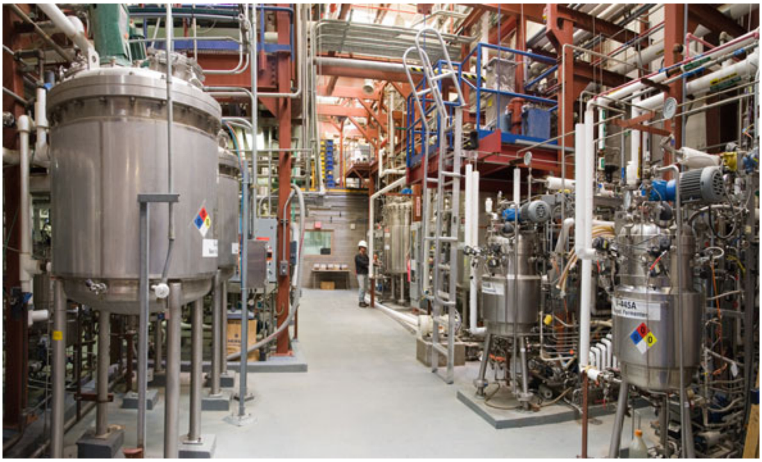


Fig. 6.15 Pilot plant to obtain Ethanol from biomass (this is a photograph from Pat Corkery, Inc/ NREL 16330)

bioalcohol and the most popular bioalcohol, but there are other biofuels like methanol which can also be bioalcohols.

Biodiesel gained a lot of popularity in the last few decades due to the rising price of oil and the fact that it can be used in any diesel engine. Algae biofuel is primarily used in the process of producing biodiesel fuel. Transesterification, the chemical process of making biodiesel, is also a relatively simple and well-understood process. The process is stable and not nearly as hazardous as the production of petro-diesel. The production process also produces little or no noxious gasses to pollute the air around the refinery.

In any algae oil production system, the algae are harvested from the growing process as algae paste. It is then de-watered either by heat drying or de-watering presses. Centrifuges are also another way in which the algae past can be de-watered. The biofuel is then separated from the paste wither by a chemical process or by pressing in a high pressure device such as a screw press. The finished product is algae oil in a form that is then suitable for use in the transesterification process to make biodiesel fuel (see the Fig. 6.16).

The finished product, biodiesel, is an environmentally friendly, renewable fuel with little or no noxious gas release during the process of combustion (see the Fig. 6.17). The production of biodiesel requires one-eighth of the energy required to produce ethanol and is usable in its undiluted state. The demand for biodiesel for use in all sectors now serviced by petro-diesel is projected to grow at an exponential rate.

Biogas is obtained by exposing organic matter to microbes. Methane is one of the most popular biogases. One popular method of producing methane is by using an anaerobic digester (essentially a cylinder with the proper microbes) filled with cow manure allowing cattle ranchers to produce energy from manure.

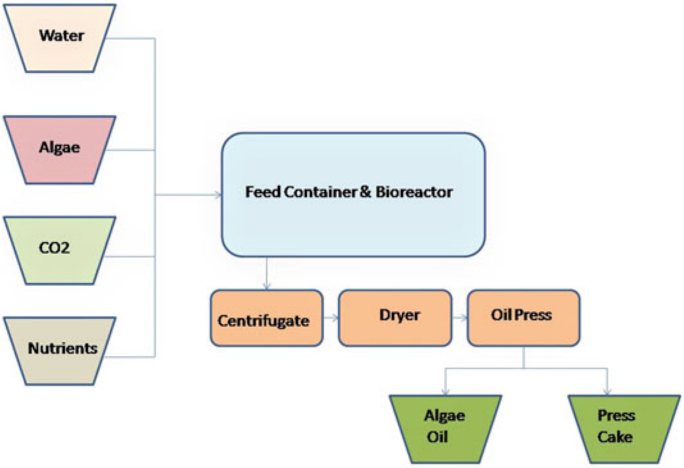


Fig. 6.16 Algae oil production system

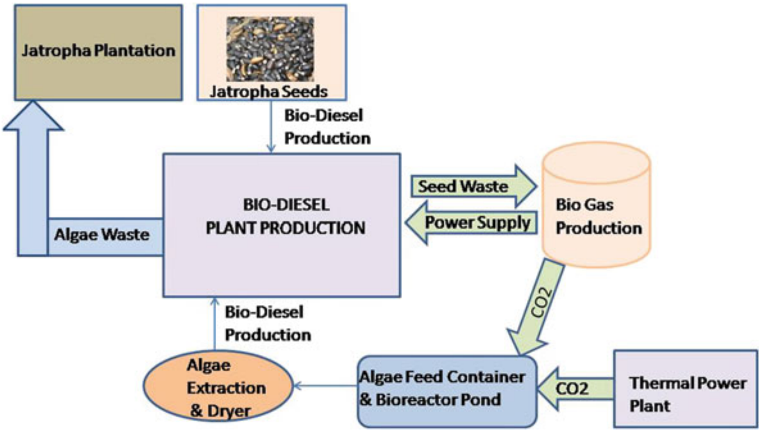


Fig. 6.17 Production of biodiesel

Syngas (*synthetic gas*) is produced by combustion of biomass in an environment that is low in oxygen. Instead of igniting, when the temperature is increased past the combustion point, the organic matter being used will begin to produce syngas. Normal combustion produces carbon dioxide and water, but syngas is actually carbon monoxide, hydrogen, and hydrocarbons. This mixture is a more efficient energy source when combusted than simply burning the original organic matter and using the heat energy.

There are many emerging biological energy sources that are not being utilized outside of laboratory and research settings. Genetically modified crops and microbes is one of the most promising of these technologies so far. Crops can be genetically modified to produce ideal biomass such as increasing sugar, oil, or carbon levels in the plant. Algae and other microorganisms are being modified to produce biofuels.

6.4.4 Robotics in BioEnergy

There is no doubt that bioenergy sector is opening new markets by using robotics technologies. Investments' aim is to develop advanced techniques and research on bio-engineering, biological process control, biosensing and robotics, bioenergy production, and bio-farming in outer space, by making greater use of life functions themselves.

In this section, some robotics applications looking for investors in biological energy are briefly presented.

- *Virtual production strategies in forestry industry.* (Freund and Rossmann 1999) In order to meet the needs of bioenergy in the coming years, sustainable forestry must become more efficient. Therefore, it has been proposed virtual production strategies, which are well-established in manufacturing, into the forest. By simulating processes beforehand, cost-effectiveness of various strategies can be estimated and the best strategy can be chosen. Furthermore, the visualization allows an intuitive understanding of the simulation results. First steps to integrate robotics know-how with geo-information technology have already been taken by enhancing a forest machine simulator in the way that the virtual forest the machine is working in, may be generated online, based on a topographic map.

- *Floating Robotics Algae Farms.* A new company called BEAR Oceanics (Beargroup) is developing small algal biofuel farms the size of bathtubs that would operate like fleets of robotic, self-contained, biofuel producers, floating in remote-controlled areas of the ocean. That vision aims for self-sustaining robot farms capable of steering clear of boats or ships and relying solely on wind and solar power to grow algae year-round.

The BEAR robotic farms are intended to turn algae sludge into five gallons of biofuel per day, employing a mild electric current to burst the algae cells to release lipid and the thermal depolymerization, using heat and pressure, to turn the algal oil into biodiesel. This will speed up the geological process that created Earth’s fossil fuels and all without the risks of drilling for oil or fracking for natural gas. This process allows turning biomass into a biofuel and any chemical is used in the process.

The biofuel farm contained only a small wind turbine, solar panel, and container of green scum packed within a tub-size frame floating on the water. But its design could someday spawn fleets of robotic farms that harness the ocean winds and sunshine to make cheap, algae-based biodiesel fuel for cars, trains, and aircraft.

- *Robotics molecular biology platform for bioenergy applications.* The molecular biological techniques for plasmid-based assembly and cloning of gene open reading frames are essential for elucidating the function of the proteins encoded by the genes (Huhes et al. 2011). High-throughput-integrated robotic molecular biology platforms that have the capacity to rapidly clone and express heterologous gene open reading frames in bacteria and yeast and to screen large numbers of expressed proteins for optimized function are an important technology for improving microbial strains for biofuel production. The process involves the production of full-length complementary DNA libraries as a source of plasmid-based clones to express the desired proteins in active form for determination of their functions. Proteins that were identified by high-throughput screening as having desired characteristics are overexpressed in microbes to enable them to perform functions that will allow more cost-effective and sustainable production of biofuels. Because the plasmid libraries are composed of several thousand unique genes, automation of the process is essential. The design and implementation of an automated integrated programmable robotic workcell capable of producing complementary DNA libraries, colony picking, isolating plasmid DNA, transforming yeast and bacteria, expressing protein, and performing appropriate functional assays is an important task. These operations will allow tailoring microbial strains to use renewable feedstocks for production of biofuels, bioderived chemicals, fertilizers, and other coproducts for profitable and sustainable biorefineries.

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